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SOIL ANALYSIS

IN an article which recently appeared in *Chemistry and Industry**, Dr. G. W. Robinson, Professor of Agricultural Chemistry at the University College of North Wales, Bangor, and Director of Soil Surveys for England and Wales, outlines the objects and methods of simple chemical analysis as applied to soil samples during the course of a soil survey, or procured for the purpose of advising farmers on manurial questions. Both these reasons are responsible for the increasing interest that has been shown by farmers in Great Britain during the present war period. Professor Robinson's account is not only philosophical but critical and constructive. It stresses the well known but often forgotten fact that laboratory work alone is very inadequate, and that, not only a wide knowledge of the practice of agriculture is needed but also considerable experience of the soils and crops of an area is essential before the results of soil chemical analysis can be successfully applied to the problems of agricultural production.

If, says Professor Robinson, an intelligent farmer were asked to state the purpose of soil analysis he would probably say: to find out what the soil is deficient in. This, indeed, has been the main motive in carrying out soil analysis and it has a special significance in face of war-time agricultural problems. Yet, soil analysis has a wider meaning: broadly speaking, the object of analysing the soil, or indeed any substance, is to obtain a description or specification of the material in unambiguous and quantitative terms. It will be only a partial description, because one cannot hope to characterize a soil completely, and even those characters or properties of the soil that are measured are only imperfectly understood. But this lack of finality is the common disability of all efforts to reduce nature to formulae. For example if we do the obvious thing and determine in the soil the percentage of silicon, aluminium, iron, and all the other elements that may be present we know very little—as little as we should know of a living being after performing the same kind of analysis.

Soil is something more than a mere mixture of mineral and organic materials. As it forms a link between the living creatures sustained by it and the rocky crust from which it is itself derived, so in some respects it may be considered as a living

* Vol. 62, No. 19, 1943, pp. 171-173.

body with differentiation of parts. Thus we may speak of soils not simply as materials, but as definite entities. Our unit of study is the soil profile, that is, the stratified succession of horizons viewed in vertical section from the surface down to and including the parent material from which the soil has been developed. To describe a soil we must, therefore, describe the succession and arrangement of the horizons making up the profile. This involves a description of the external morphology as viewed in the field, and also the chemical, physical and microbiological study of the constituent horizons. And even when this has been done we have still to trace the processes within and the exchanges between the soil horizons, processes analogous to the functional processes in animals and plants. It is thus no simple matter to analyse the soil, if by analysis is meant a complete description of the soil considered as a natural body.

We may now consider the aims of soil analysis. Soil may be investigated or analysed for one or both of two reasons. In the first place we may seek by our analytical examination to obtain a description that will completely define the soil. Such a description is necessary and desirable in order to assign a soil to its position in a system of soil classification. The aim of such analysis is to exhibit the permanent constitution of the soil rather than the variable characters impressed on it by the vicissitudes of agricultural use. It involves mechanical or particle-size analysis, fractionation of the organic matter, and the chemical and mineralogical examination of the clay fraction, as well as certain other critical chemical and physical determinations. This is soil analysis as an aid to the purely philosophical study of the soil. Yet in learning to know and classify our soil we may hope to find principles that will emerge in applications to practical agriculture.

Coming now to the more immediately practical object of soil analysis, namely the assessment of nutrient deficiencies, it must be admitted that the position is far from satisfactory. This, however, is only to be expected from the great complexity of the problem. Apart from the great gaps in our knowledge of the constitution of the soil, far too little is known of the mechanism of absorption of nutrients by the roots of plants. It is quite certain that in normal soils absorption differs considerably from that in culture solutions. We cannot, therefore, hope to assess the nutrient status of a soil by isolating and analysing the soil solution, although under certain circumstances such a procedure might give useful indications.

In the early days of agricultural chemistry it was thought quite naturally that the status of the soil with respect to any particular nutrient element was reflected by the amount present. This proved too easy a generalization and it became recognized that there was a distinction between available and unavailable nutrients. Thus, a soil might contain several thousand pounds per acre of nitrogen and yet the supply may be quite insufficient for the needs of a crop requiring only about 50 lb. per acre of that element. The chemistry of soil analysis during the past half century has mainly consisted in the search for methods of determining available plant nutrients in the soil. The principle underlying the use of these methods is the supposition that if any method of extraction is used whereby only a small proportion of a given element is extracted, then this extracted fraction represents the most active and available category. It should be understood, however, that the distinction between available and total is not absolute. If we say, for example, that a soil contains 0.02 per cent. available P_2O_5, it must not be thought that the remainder of the P_2O_5, amounting possibly to 0.2 per cent., is unavailable, or even that all the so-called available is, in fact, available. It is rather a distinction between the more and the less available, and we may look upon the unavailable as a reserve, which under certain conditions may be partially mobilized.

So far, then, as methods for determining available nutrients have a theoretical basis, they rest on the assumption that by limited extraction with weak acid, or, in some cases, weak alkaline solvents, a small fraction of relatively active and, therefore, available plant nutrient is brought into solution. The Dyer citric acid method for available phosphorus and potassium may serve as an example. The choice of one per cent. citric acid as a solvent represented an attempt to imitate the solvent action of the root sap of plants. Apart from the questionable character of this assumption, it is evident that the fraction extracted by the Dyer method represents no definite category of soil phosphorus. By varying the ratio of solvent to soil, and the temperature and time of extraction, varying amounts of phosphoric acid can be extracted from the same soil. The method is, in fact, purely conventional, and the analytical figure must be considered rather as an index of availability than as a measure of the amount of phosphorus or potassium actually available. The choice of an extracting reagent, however, is only the first step towards establishing a method of analysis. Having settled the details of the method, there remains the more difficult task of deciding what the results mean for practice. For example if we are examining a soil for an element x and we have decided to use a weak acid extractant under specified conditions, we may find that a certain soil gives 0.010 per cent. of this element. By itself the figure is meaningless, because it is necessary to determine, by the examination of a large number of soils of known behaviour, what constitutes deficiency and what excess. This is indeed the most difficult problem in soil analysis, for the limiting value, below which deficiency occurs, will depend on the character of the soil itself, on the moisture and temperature conditions within the soil, on the weather, and on the particular crop to be grown.

Given the complexity of the problem it is not surprising that the correlation between laboratory results and field behaviour has never been completely established for any analytical method. Such correlations as have been worked out are generally imperfect and only approximately valid for a limited range of soil, climate, and cropping. The partial success of these admittedly empirical methods has depended on their restriction to particular types of soil and agriculture. To take the case of soil phosphorus, there is in different parts of the world a wide variety of methods of determining availability, each of which has proved useful under particular conditions and in the light of local experience. No generally accepted universal method exists or seems likely to be developed. Even if a universally approved laboratory method were devised it would still be necessary to interpret the results in the light of local conditions.

We may now look at the problem from a different angle. Granted that a method, admittedly empirical, has been devised for the determination of a given plant nutrient and that, by correlation of laboratory results with field behaviour, it is possible to assign standards for deficiency, normality, and excess, what use is to be made of analytical data in practice? Obviously, they should serve as the basis of recommendations for the use of manures and fertilisers. Here, however, we must distinguish a little. We must distinguish between what might be called general manurial policy, the use of manures and fertilizers for maintenance of fertility and the repair of losses through normal wastage and the sale of crops on the one hand, and on the other, the needs of particular crops. The distinction is essentially between the long-term and the short-term policy. Soil analysis has much less to say about the long-term than about the short-term policy, for the long-term manurial policy will be dictated mainly by the system of management and cropping under the particular local conditions of soil and climate. So far as it can be ascertained by experiment it will be more securely based on adequate field experiments than on soil analysis. Soil analysis does, however, play a useful part in indicating what basal amendments are necessary to bring the soil up to the level at which a long-term manurial policy may be put into operation. For example, with ley-farming and livestock or dairy husbandry, it might be possible to maintain a satisfactory level of production by a very moderate use of purchased fertilizers. Before this moderate use could be recommended as a manurial policy it would be necessary to bring the soil up to normal status in lime, phosphate, and other plant nutrients. It is here that soil analysis might be expected to help by ascertaining deficiencies and furnishing the necessary information for prescribing basal dressings.

The use of soil analysis to ascertain the needs of a particular crop is somewhat different. For example, potatoes and oats can tolerate a lower lime status than barley, wheat, or lucerne. Cereals can tolerate a lower phosphate status than swedes. And thus from the standpoint of the needs of a single crop an analysis may suggest a manurial treatment different from that demanded by considerations of long-term policy. In practice, however, this distinction is not so clear cut. For example, a farmer may be growing a crop of oats on a lime-deficient ploughed-out ley. Although the oat crop may not itself need lime, it may be followed by a crop such as barley, and, therefore, a lime dressing may be advised, particularly because it will help to rot down the old turf and contribute indirectly to the success of the oat crop.

When we turn to the more intensive utilization of the soil, the analysis of the soil for the assessment of manurial deficiencies probably recedes in importance. This is particularly the case in horticultural work such as, for example, tomato culture in glass-houses. Here, the soil tends to be mainly a physical medium and the problem is rather to determine the optimum manurial dressings independently of the plant nutrients originally present. Unsatisfactory results in intensive horticultural production can rarely be diagnosed by soil analysis; they are generally due to lack of balance in manurial dressings or defects in water supply. The logical end-point of intensive glass-house production would appear to be the use of culture solutions in sand or gravel media.

Having attempted to explain the difficulties of soil analysis and the inadequacy of our knowledge, the state of our actual practice may now be reviewed. In the first place, it should be noted that although the elements obtained from the soil by the roots of plants amount to a dozen or more—" or more " because the list is always being extended—in actual practice the agricultural chemist generally confines his attention to three, namely, calcium, phosphorus, and potassium, because, in the great majority of soils, one or more of these are most likely to be present in deficient supply. Nitrogen deficiency is also a common, perhaps the commonest, cause of unsatisfactory production, but it is not included in the soil analyst's list because no routine analytical method has yet been established for the accurate assessment of nitrogen deficiency, although several have been proposed.

One of the most important tasks of soil analysis is the assessment of lime status. Deficiency of lime in the soil implies acidity. The crude litmus paper test has long fallen into disuse, but it has been replaced by a great variety of methods designed to measure soil acidity. In other words, in assessing the lime status of soils, agricultural chemists have generally preferred to estimate a supposed lime deficiency rather than the amount of lime actually present. In this course they have probably been influenced by the greater convenience of estimating acidity, and indirectly by the theory, as yet unproven, that when soils are deficient in lime, the efficient factor limiting production is acidity . . .

The determination of available phosphorus in soils is generally based on weak acid extraction; although at least one weak alkaline extraction method has been proposed. In this country the Dyer method, using one per cent. citric acid, is still widely used and although its theoretical foundation is perhaps unsound, so much practical experience of it has been accumulated that agricultural chemists are reluctant to abandon it. The main disadvantage, (and this applies equally to other methods) is the very broad penumbra between clear deficiency and clear sufficiency. Thus, in ordinary soils, with 70 parts per million or less P_2O_5, one can be fairly sure that most crops would benefit by phosphatic dressings. With more than 200 p.p.m. P_2O_5 cereal crops would not be in need of added phosphate and ordinary maintenance dressings would suffice for root crops.

Available potassium can be determined also by the citric acid method. The theoretical basis is slightly better than in the case of the same method for phosphorus, because the potassium extracted corresponds very nearly with a definite category, namely the exchangeable potassium. In practice, the tendency now is to replace the Dyer method by the determination of exchangeable potassium, using normal acetic acid as an extractant. Here again, as in the case of phosphorus, there is an inconvenient penumbra, but on soils with less than 70 parts per million exchangeable K_2O the possibility of crop failures from potassium deficiency may be reckoned with.

The agricultural chemist in future will probably have to pay more attention to the so-called minor elements in the soil. Unfortunately, the position with regard to their determination is even more unsatisfactory than in the case of the main elements. It is true that there are methods for determining these elements; their weakness lies in the correlation of the results with field observations. For example, we can determine the percentage of boron in the soil; we can go further and determine the percentage of boron soluble in a standard acid extractant, or in water; but until the results have been correlated with field behaviour under a variety of soil, climatic, and agricultural conditions, they are almost meaningless. Before leaving the discussion of chemical analysis, brief reference should be made to the use of rapid field methods for determining nutrient deficiencies . . . . In the first place there are the methods based on the analysis of crops. Originally used by Liebig, crop analysis for the purpose of assessing manurial requirements has had rather a chequered history, but of recent years it has received greater attention and there is no doubt that useful indications can be given with selected plants, if the stage of growth is taken into consideration. A new impetus has been given to this type of investigation by the introduction of spectroscopic methods, particularly for the discernment of deficiencies in minor elements. The method is full of promise, but problems of interpretation must be solved. The fact that a particular element is present in sub-normal amount does not necessarily imply a deficiency in the soil. It may be the result of disturbance in physiological balance. The method of Neubauer, whereby the nutrient status is deduced from the composition of young rye seedlings grown on the soil has been widely used abroad and with fairly satisfactory results. Its popularity on the continent is shared with the Mitscherlich method in which nutrient deficiencies are ascertained by pot experiments. But the Neubauer and the Mitscherlich methods have the disadvantage of being somewhat laborious and expensive. Finally, there is a group of methods depending on observations of the growth of the mycelia of certain fungi, *e.g.*, *Aspergillus niger* in culture solutions in the presence of soil. These methods, like the Neubauer and Mitscherlich methods, have the merit that they test the behaviour of the soil itself as a medium for growth. Whatever their promise for the future, it cannot be claimed that they have yet secured general approval as routine methods.

From this account, soil analysis may appear to the non-agricultural chemist as something of an Augean stable. . . How shall the Augean stable of soil analysis be cleansed? In the first place, we must know more of the constitution of the soil and of the processes within the soil. Secondly, or bracketed firstly, we must know more of the actual mechanism of plant nutrition in the soil. When we know more of the soil itself we may proceed to build up a corpus of analytical methods that will serve to define the actual soil conditions and not merely give general indications. This will mean the replacement of many of the existing conventional methods by absolute methods. For example, the Dyer citric acid method gives very useful indications in practice, but nobody can say what actual fraction of soil phosphorus is extracted by one per cent. citric acid. We must, therefore, discover that which we do not know at present, namely, what categories of phosphorus are actually present in the soil, and having ascertained the rôle of these different categories in plant nutrition, we must assess nutrient status with respect to phosphorus from the results of an actual fractionation.

Finally, we need more trustworthy information on the field behaviour of soils. Nowhere is the truth more difficult to discover than in agriculture. If we knew all about the constitution of the soil and about the nutrition of plants, we might dispense with field experiments. Until that distant day, we must rely on well-planned field experimentation to give us the field side of our laboratory story. Only when field behaviour has been correlated with analysis will it be possible for the agricultural chemist to answer the farmer's enquiry and assess the soil's manurial deficiencies.

CACAO SELECTION ON THE GOLD COAST

BY

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At the commencement of the selection programme in 1937, yield was the first consideration, with the object of maintaining the quantity of exports despite the decrease in the area of land growing cacao, as old farms die out in areas where disease or soil deterioration renders replanting impracticable. Bean size was also taken into account. Later, after a large number of farms in most of the chief cacoa-producing areas in the Colony, Ashanti and Togoland had been surveyed for high-yielding trees, it was concluded that any improvement in quality and yielding capacity of planting material would be useless unless the Swollen-shoot virus and the Capsids (*Sahlbergella* spp.) could be controlled.

In view of how limited the distribution of Swollen-shoot then appeared to be (12), and the possibility that some of the selected trees were high-yielding because of tolerance to Capsid attack, it was decided that the earlier selection work should not be abandoned, but that trials should be started with the most promising selections. Since September, 1940, however, selection work has been concentrated on the search for trees resistant to Capsids and virus diseases, and this is a convenient time to present the results of the earlier programme aimed at the improvement of yield and quality.

Available Material

The type of cacao predominant in West African farms has been called "Amelonado" for many years, but it must be distinguished from the trees with Amelonado-shaped pods which segregate from the Trinitario hybrid types. The West African "Amelonado" breeds true to type, is uniformly high-yielding (1,9), almost invariably self-compatible, and exhibits very little, if any, tree-to-tree variation which can yet definitely be called genetical; probably it came originally from Surinam via the island of Fernando Po, and rumour holds that only a single pod was introduced to the Gold Coast about 1880. For several years this Amelonado type was thought to be identical with *T. leiocarpa* Bern. (6) and is referred to as such in the writer's previous publications, but recently Cheesman (7) has given reasons for doubting the validity of this name.

The Amelonado variety is sometimes considered (5) to be the origin of the disease-resistance of Forastero cacao, and has certainly proved well suited to West Coast conditions. Being apparently less susceptible to attack by *Phytophthora* spp. it can be grown under conditions of higher humidity and denser shade than can the Criollo types, without suffering unduly from canker and pod rot. It is to be expected, however, that some of the hybrids will prove to be even hardier than pure Amelonado, which is certainly less vigorous than most Trinitario types.

The usual objection to the Amelonado variety concerns its bean, which has neither the plumpness nor the intrinsic quality of the Criollo types. This is counteracted to some extent by uniformity, because although well below the "fine" types at their best, the West African cocoa is without the very small beans segregating from the Trinitario complex. Gold Coast sampling figures (4) show that an average of 426 beans make 1 lb. dry cocoa. At the normal rate of 40 beans per pod this is just over 10 pods per lb. Even when allowance is made for the Trinidad mean of 35 beans per pod it is plain that the average West African bean is little lighter than the average Trinidad bean *; yet the latter commands a much higher price because it has some very large beans in the mixture, because of its indefinable "intrinsic quality", and because of the African producers' reputation for poor curing.

Although the first botanical work on Gold Coast cacao was started in 1937, the foundation for a selection programme was laid by individual tree yield-recording at Aburi since 1914, at Asuansi and Kumasi since 1919, and at Kpeve since 1928. On the basis of plot yields taken at several agricultural stations (1) the true-breeding West African "Amelonado" variety was regarded in 1926 as the type best suited to Gold Coast conditions, and individual-tree-recording was restricted to "Amelonado" plots. This decision came too late to have any effect on type of cacao grown by Gold Coast farmers, most of whom had little choice. The Amelonado variety was well distributed before other introductions (confined to the Agricultural Department stations) came into bearing. The attempts of the Agricultural Department to distribute seed of better quality types were neither so commercialised nor so extensive as those of the itinerant trader. In more recent years the trader has played some part in distributing hybrid varieties. Several farmers have admitted paying a high price (£1 per pod is probably an exaggeration) for particularly huge pods which have produced mostly self-incompatible trees with a poor yield of big pods.

The only plots of Trinitario introductions now remaining on experiment stations came from River Estate, Trinidad in 1905, 1906 and 1909. In 1937 (11) it was shown that most of the trees on the "Cundeamor" and "Criollo" plots at Aburi were self-sterile, and later yield-records

* Trinidad average is 12 pods per lb. dry cocoa.

confirm that a few self-compatible trees contribute a very high proportion of the yield. Consequently it was decided that selection should be restricted to the pure Amelonado type, which from the breeder's view-point, shows a depressing uniformity in yield and quality. Individual-tree-yield recording was started in 1938 at Aburi and Asuansi on plots called "Cundeamor", "Ocumare", Red and Yellow "Criollo". After self-incompatible trees had been eliminated, the population was inadequate for selection purposes, so a survey of native farms was carried out over most of the important cocoa-producing districts in the Colony and Ashanti. This revealed an unexpectedly large number of farms with more than 30 per cent. Trinitario trees. Many trees seemed too old to have originated from the River Estate, Trinidad, introduction, and it must be assumed that the earlier introductions left their mark. An Aburi Gardens list dated 1906 (8) states that "Caracas White Cacao" and "*T. pentagona* white cacao", among other types, were available for distribution. Many farmers obtained seed, not direct from an Agricultural Station, but from other native farms, where further hybridisation with Amelonado has probably occurred.

In all farms visited, there is nothing to suggest that hybrid trees are less suited to the soil and climate than the pure Amelonado type, while pod damage by *Sahlbergella* and disease at Tafo even indicates the reverse. In Table I the yields of 29 hybrid trees are compared with the same number of Amelonado trees selected at random in each plot. The lower total yield of the hybrids can be attributed to their being much younger trees. From statistical analysis of these figures the conclusions are :—

Discards due to Black Pod are significantly less on hybrid trees, but the set of results are internally contradictory (cf. Plot C62 and totals). The apparent significance between types is not supported by a consideration of the variation shown between plots, which is significant.

Capsid Pod Damage : There is (a) no significant difference between hybrids and Amelonado, (b) no significant difference between types in the same plot, (c) very significant difference between plots.

Genetical Variation

The yield variation in Trinitario cacao has been investigated by Pound (13), and as one would expect, that of the same type of cacao introduced from Trinidad appears to be similar on the Gold Coast, if due allowance is made for the much smaller tree-population. In the Amelonado type, however, only the variation in number of pods per tree had been recorded (2, 3) and before a reliable method of selection could be adopted, the variation in pod-weight and in bean-number per pod required investigation. Trees with unusually large or small Amelonado-shaped pods appear invariably to be segregates from the Trinitario mixture. The presence of other typical segregates near by, usually supports this contention, while the absence of Calabacillo trees from pure Amelonado farms suggests that that genotype does not segregate from the Amelonado, but only from the Trinitario introductions. This and many other questions of genetical interest should be elucidated by the progeny trials to be described later.

In July and August 1938, a detailed survey of the Tafo cacao was made by counting and weighing beans from a random sample of 10 pods from each of 900 Amelonado trees selected at random. This was repeated in December to show up the seasonal trend. The results are summarised in Figures 1 and 2, from which it is clear that mean bean-number per tree remains constant throughout the season with comparatively little tree-to-tree variation, while the mean pod-weight decreases from under 10 to over 11 pods per lb. dry cocoa ; here again the variation between trees is relatively small compared with Trinidad figures (13), especially considering the differences in age, spacing

TABLE I

Plot	No. of Trees	Hybrids			Amelonado		
		Pods			Pods		
		Harvested	Diseased	Capsid Damaged	Harvested	Diseased	Capsid Damaged
A 61	2	38	4	0	145	24	3
A 63	3	29	0	0	60	7	1
B 62	5	28	1	0	98	25	15
E 54	3	46	8	4	107	16	11
C 61	2	8	0	5	12	2	10
C 62	10	126	21	18	123	9	16
C 64	4	58	6	41	81	30	25
Totals	29	333	40	68	626	113	81

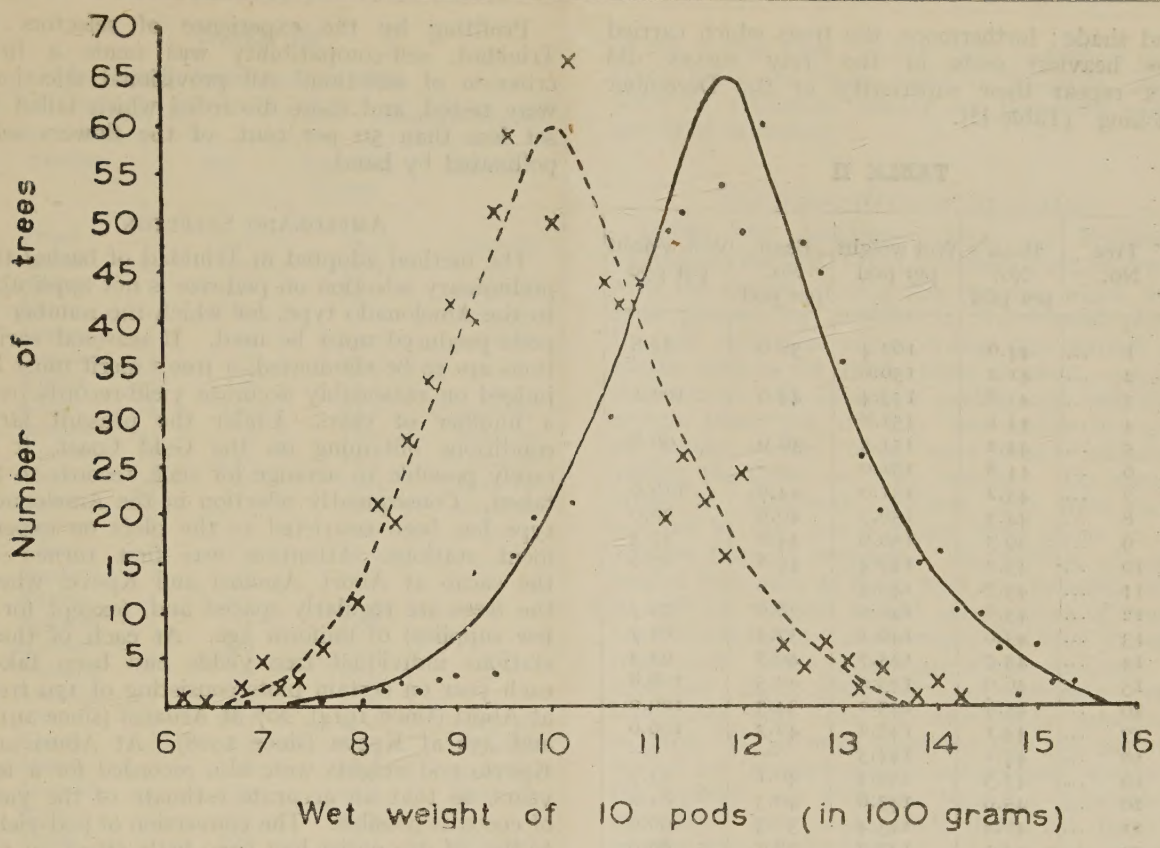

FIG. 1. Weight of wet beans from 10 pods per tree (dotted line—December; continuous line—July)

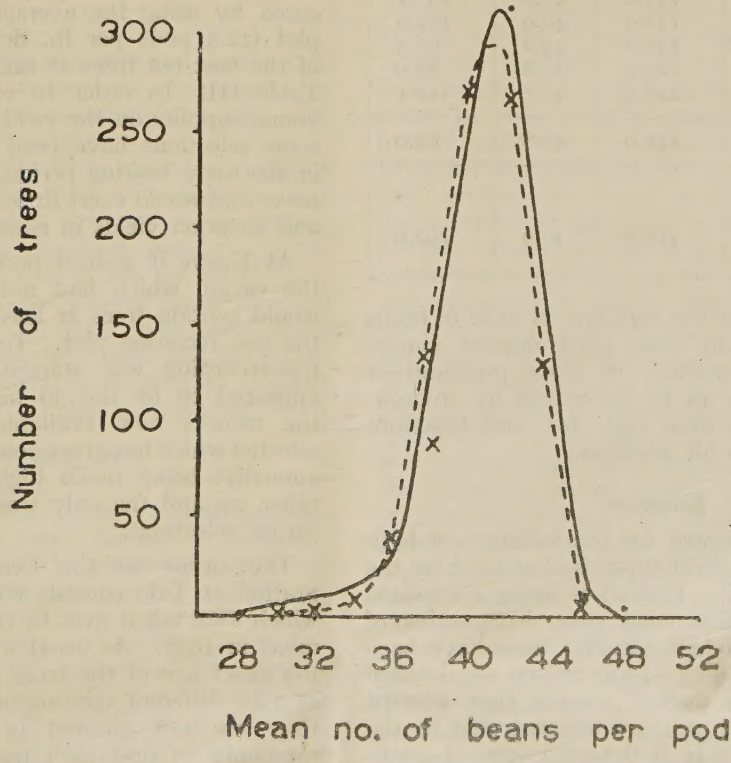

Fig. 2. Mean number of beans per pod from 10 pods per tree (dotted line—December; continuous line—July)

and shade; furthermore, the trees which carried the heaviest pods in the July survey did not repeat their superiority in the December picking (Table II).

TABLE II

Tree No.	Bean No. per pod	Wet weight per pod	Bean No. per pod	Wet weight per pod
1 ...	44.6	162.4	36.6	82.8
2 ...	41.2	156.6	—	—
3 ...	43.8	153.4	44.8	102.1
4 ...	44.1	151.8	—	—
5 ...	44.2	151.3	38.6	96.8
6 ...	44.8	151.0	—	—
7 ...	43.2	151.0	44.0	116.6
8 ...	44.2	150.7	40.0	70.0
9 ...	39.5	150.6	44.0	77.5
10 ...	45.2	147.4	45.8	87.2
11 ...	43.7	147.5	—	—
12 ...	45.8	140.9	38.0	79.7
13 ...	43.6	146.1	37.5	68.7
14 ...	43.7	145.7	40.7	93.3
15 ...	46.0	145.2	42.5	108.8
16 ...	41.6	145.2	34.3	100.0
17 ...	44.1	145.2	42.3	106.6
18 ...	44.2	144.5	—	—
19 ...	43.5	144.4	40.1	81.7
20 ...	45.6	143.8	40.3	82.2
21 ...	48.4	143.4	38.3	90.9
22 ...	44.1	143.2	38.5	88.6
23 ...	41.3	143.0	—	—
24 ...	45.3	142.8	39.8	80.7
25 ...	42.7	142.5	39.2	93.7
26 ...	42.8	142.2	43.0	107.1
27 ...	44.9	142.0	46.9	102.0
28 ...	38.7	142.0	44.2	90.5
29 ...	39.1	129.4	37.8	83.9
30 ...	38.8	128.5	41.7	111.1
Mean ...	43.4	146.0	40.8	92.0
Mean of 900 trees ...	41.7	116.0	40.9	102.0

This showed that the variation in yield of beans between Amelonado trees must depend almost entirely on the number of pods produced—a factor more likely to be influenced by environmental conditions than pod size, and therefore a less reliable basis for selection.

Selection

The method adopted for the selection of both Amelonado and hybrid types is that used by the Dutch in Java (14). Instead of fixing a standard which each selection must pass, irrespective of its locality, the highest yielding trees have been selected in each plot or farm chosen for detailed observation. This method ensures that selected trees are scattered and not concentrated in the best environment. It is the only method applicable to native farm cacao, with its irregular spacing and widely different degrees of cultivation.

Profiting by the experience of selectors in Trinidad, self-compatibility was made a firm criterion of selection. All provisional selections were tested, and those discarded which failed to set less than 50 per cent. of the flowers self-pollinated by hand.

Amelonado Selecton

The method adopted in Trinidad of basing the preliminary selection on pod-size is not applicable to the Amelonado type, for which the number of pods produced must be used. If seasonal variations are to be eliminated, a tree's merit must be judged on reasonably accurate yield-records over a number of years. Under the peasant farm conditions obtaining on the Gold Coast, it is rarely possible to arrange for such records to be taken. Consequently selection in the Amelonado type has been restricted to the plots on experiment stations. Attention was first turned to the cacao at Aburi, Asuansi and Kpeve, where the trees are regularly spaced and, (except for a few supplies) of uniform age. At each of these stations individual tree yields had been taken each year on certain plots consisting of 179 trees at Aburi (since 1914), 207 at Asuansi (since 1919) and 256 at Kpeve (since 1928). At Aburi and Kpeve, pod-weights were also recorded for a few years, so that an accurate estimate of the yield of cocoa is possible. The conversion of pod-yields to lbs. of dry cocoa had very little effect on the order of merit of the trees, so for uniformity in presentation the yields of Asuansi selections have been converted from number of pods to lbs. dry cocoa by using the average pod weight for the plot (12.5 pods per lb. dry cocoa). The yields of the best ten trees at each station are given in Table III. In order to offset the influence of young supplies on the yield of neighbouring trees, some selections have been chosen on the yields in the early bearing period, when vacancies were fewer and would exert little effect at wide spacing, and some on yields in recent years.

At Kpeve it seemed probable that the rest of the cacao, which had not been yield-recorded, would contain trees at least as good as those on the one recorded plot. To test this, individual-tree-recording was started in 1938 on what appeared to be the 30 highest yielders. From the records now available one tree has been selected which has given consistently over 100 pods annually, being much higher yielding than the other 29, and the only tree comparable with the earlier selections.

The cacao on the Central Cocoa Research Station at Tafo consists entirely of native farms which were taken over by the Agricultural Department in 1937. As usual with this type of farm, the exact age of the trees is unknown, and trees of quite different ages are often growing together; they are not planted in lines, but scattered randomly so that each tree occupies a different space. Comparison between trees is further complicated by the interspersal of numerous indi-

TABLE III

Amelonado Selection Data 1938

Selection		Mean Annual Yield	
Station	No.	Lbs. Dry Cocoa	Period
Aburi ...	121	15.2	1927-36
Aburi ...	139	15.2	,,
Kpeve ...	5/8	14.2	1932-36
Aburi ...	187	13.6	1927-36
Asuansi ...	45	13.5	1932-36
Asuansi ...	53	13.3	,,
Kpeve ...	4/6	13.1	,,
Aburi ...	164	13.1	1926-36
Asuansi ...	5	13.0	1919-26
Kpeve ...	5/12	12.8	1932-36
Aburi ...	20	12.3	1914-26
Kpeve ...	3/15	12.2	1932-36
Kpeve ...	7/10	12.0	,,
Kpeve ...	3/9	11.9	,,
Asuansi ...	70	11.8	,,
Kpeve ...	3/7	11.5	,,
Asuansi ...	72	11.6	,,
Kpeve ...	4/9	11.2	,,
Asuansi ...	52	10.9	,,
Asuansi ...	84	10.8	,,
Aburi ...	263	10.6	1927-36
Kpeve ...	2/7	10.5	1932-36
Aburi ...	218	10.5	1914-26
Asuansi ...	115	10.4	1932-36
Kpeve ...	3/5	10.4	,,
Aburi ...	176	10.3	1927-36
Aburi ...	**220**	**10.3**	**1914-26**
Aburi ...	**196**	**9.8**	**,,**
Asuansi ...	43	9.6	1919-26
Asuansi ...	132	7.0	,,

genous forest trees of various ages and species (15). No method has been devised to compensate for all these factors, and their interactions with age has been assessed only as girth.

As there appears to be little variation in vigour in the Amelonado type, there is probably a close correlation between girth and age. The bearing trees were therefore classified into 1″ girth-classes—2″-3″, 3″-4″ and so on up to 40″-41″. The yields of 24,972 trees were then recorded individually, starting in 1938. After two years, the mean yield for each girth-class was calculated and the highest yielders in each class selected for further recording. Table IV shows the yields

TABLE IV

Selection No.	Girth at 3 ft. (1939)	Mean Pods per year 1938-1940	Mean Dry Cocoa per year	Mean yield (pods) of girth class
T 3 ...	16″	132	11.43 lbs.	35.5
6 ...	20″	178	15.50 ,,	44.5
4 ...	26″	183	15.95 ,,	44.6
9 ...	25″	188	16.32 ,,	58.1
7 ...	24″	205	17.82 ,,	48.1
5 ...	24″	208	18.05 ,,	48.1
8 ...	32″	237	20.64 ,,	70.6

of the 7 best trees; as the yield of each is over three times the mean yield of its girth class, there is statistical reason for supposing some genetical influence.

Trinitario (Hybrid) Selection

Unlike the Amelonado type, no Trinitario hybrids on the Gold Coast had been yield-recorded with the exception of a few supplies which had been planted by mistake in Amelonado plots. In 1938 individual-tree-recording was started on all the trees in the hybrid plots at Aburi—a total of 160 trees. At Asuansi a preliminary selection of 36 trees out of 679 was made by eye. 46 young hybrid trees were found scattered among the farms on Tafo station. On native farms at Akrokerri, Ashanti, 100 trees were selected by eye, and 8 chosen from about 70 on another farm at Potroase. The number of pods reaped from each of these trees was recorded, and in addition the wet weight and number of beans per pod was taken from a sample of at least 30 pods from each. Some figures are shown in Table V. Although these yields do not compare very favourably with those of Amelonado selections in Table III, we must remember that the records, are not for the same period, and generally speaking the hybrids are younger than the Amelonado selections. In recent years, there has been a general drop in the yield of recorded plots, which may be partly attributed to increased Capsid attack.

Generally it is impossible to obtain accurate tree-yields off native farms. In the Crop Forecasting scheme, it has been found that pod-counts taken early in the main-crop season provide a good estimate of yield with the Amelonado type, where pod-size is fairly uniform. When choosing hybrid selections for observation and compatibility test on native farms, individual pod-weights and bean-counts were recorded, and a pod-count taken in September or October. The best yielding trees with pods larger than 7 per lb. dry cocoa were then tagged for further pod-counts and compatibility tests. While these counts do not provide a true estimate of yield, they are legitimate for comparison, and clearly showed the hybrid selections exceeding the yield of neighbouring Amelonado trees of the same age. When mixed with Amelonado trees, the great-vigour of the hybrids was very noticeable. Apart from the difference in size, which was often so great that it was difficult to believe the farmer's assertion that both types were planted at the same time, the selected hybrids were in full leaf when Amelonado trees were suffering from one form of "dieback" or another. Even when no such signs of resistance were obvious, selection for high yield should ensure automatically that the tree is reasonably resistant to the pests and diseases prevalent in the locality.

Compatibility tests have eliminated a number of these selections as self-incompatible, leaving 20 native-farm selections in the final list for trial.

TABLE V

Station	Tree No.	Girth inches at 3 ft.	Pods weighed	Mean Bean No.	Mean Wet Weight Grms.	1938-39 Yield Pods	1939-40 Yield * Pods
Asuansi	19	17	59	35	124	76	81
,, ...	27	26	72	23	99	100	101
,, ...	33	19	15	41	184	53	14
,, ...	36	21	31	35	144	52	54
Akokerri	26	23	62	?	115	66	47
Potroase	2	—	30	39	129	66	78
,, ...	4	—	30	40	123	78	75
Tafo	T2	9	21	40	171	11	12
,, ...	T1	9	54	42	155	28	45
Aburi	Cr. 12	22,24	all	36	87	217	119
,, ...	,, 36	25	,,	35	80	128	39
,, ...	,, 62	27	,,	37	109	148	102
,, ...	,, 72	24,24	,,	39	98	190	119
,, ...	Cu. 45	20	,,	32	106	124	60
,, ...	,, 46	20	,,	31	140	129	19

* Partly reduced by removal of natural sets during hand pollination.

Propagation

The high yields on which trees are selected may be due to inherent characters, or to chance causes such as local soil conditions or lack of competition (weak neighbours). These factors can be eliminated only by trials, the nature of which must depend on the method of distribution to be adopted with the proved stock. As agreed at the Third West African Agricultural Conference (16), the state of cacao cultivation on the Gold Coast is such that seed only is suitable for supplying farmers; besides transport difficulties, it is unlikely that cocoa farmers will give cuttings or buddings the necessary attention. Nothing precise is known about the inheritance of yield but on genetical principles it is anticipated that some inherently high-yielders will produce progeny of a higher average yield than unselected stock. This is being tested in progeny trials of the most promising selections, using seed produced by hand self-pollination. Harland (10) reports certain Trinidad trees conspicuous for high yield in their seedling progeny even though the seed was open-pollinated.

It has been the policy, from the commencement of selection, to collect budwood, wherever practicable, immediately a tree was provisionally selected. This has saved for future observation several selections which have since died of Swollen-shoot or root disease; it also ensures a convenient source of budwood or cuttings for the establishment of clonal plots for seed-supply on a large scale.

Hand selfing is done between March and July. The beans are planted in baskets from September to January, and the seedlings kept under *Leucaena glauca* shade until the following April. The shade is then removed, and the seedlings planted out in plots during May and June. Vacancies are filled in October after the "small" dry season.

Seedling Trials

1st Progeny Trial (*Amelonado*)

28 of the Amelonado trees selected on experiment stations, together with one selection from Nigeria and one hybrid from a native farm, are being tested in a 16-acre progeny trial designed so that 192 (self-pollinated) seedlings from each parent are randomised (in sub-plots of 3 trees) with unselected seedlings as control and budlings from each parent. Four methods of establishment, six different shade trees, and no permanent overhead shade are also being tested in this trial. Sixty-four $\frac{1}{4}$-acre plots are used, in each of which cacao at 10′ 4″ by 10′ 4″ spacing gives 100 plants. A preliminary planting was done in 1939, but the main planting of this trial was done in May 1940.

2nd Progeny Trial (Trinitario Hybrids)

This is an 8-acre trial in which the selfed progeny of 35 hybrid selections and one Amelonado are being tested. 72 seedlings of each selection are randomised in 8 plots of 9 trees each. The main planting was in 1942. A trial of plantains against *Leucaena glauca* as shade is super-imposed. The spacing is 400 plants per acre.

3rd Progeny Trial

The selfed progeny of 13 Tafo selections, 1 from Aburi, and 2 native-farm selections, in randomised plots of 28 trees, are imposed on $1\frac{1}{2}$ acres of a Rejuvenation trial. Planting done in 1942 at a spacing of 5′ by 10′.

4th Progeny Trial

A area of $\frac{1}{2}$ acre is being planted progressively with seedlings from white beans, some of known parentage and some illegitimate; rows are interplanted with seedlings (to be cut out later) from purple beans as a check on growth rate. Planted in 1941 and 1942 at 5′ by 10′.

5TH PROGENY TRIAL

Selfed progeny of two Amelonado selections from Tafo stations imposed on a 2-acre Manurial trial. Planted in 1942 with transplants from beds at 10′ by 5′.

Clonal Trials

Bud-grafts of all, and rooted cuttings of some, of the selections have been established at Tafo mainly with the object of increasing the amount of budwood available. Root-stocks have been planted for the establishment of 12 acres of budded clones mostly in randomised plots of 16 trees. The chief purpose of these clones is seed production, should any of their progeny prove worthy of distribution. A secondary consideration is the behaviour of these individual clones as regards yield and disease and pest resistance. Although only seed distribution is envisaged at present, it is fully realised that it may become necessary to resort to clonal distribution, especially if the selection programme now in progress leads to clones resistant to the Swollen-shoot virus and Capsid attack.

Summary

1. A brief account is given of the cacao available for selection work on the Gold Coast.

2. The variation in the West African Amelonado variety is shown to be due mainly to the number of pods per tree.

3. The methods used, and the results of selection on experimental plots and native farms with both Amelonado and Trinitario types, are described.

4. The progeny trials laid down to test the selected trees are listed.

Acknowledgment

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REVIEW

THE AFRICAN AND HIS LIVESTOCK

By R. W. Thorton and W. G. Leckie.

African Welfare Series, Oxford University Press, 1942, pp. 72.—Price 1s. 6d.

This small book deals comprehensively yet simply with the kinds of livestock kept by natives in South and East Africa. It rightly begins with the land, stressing the need for conserving pastures, their subdivision, and the growing of fodder grass and supplements before going on to describe shortly and clearly the various types of livestock and their management. There are sections on cattle, sheep, pigs, goats, horses and donkeys and poultry. These are all written from a very practical point of view and are attractively illustrated.

A rather important section is that dealing with animal products. Africans are only now learning to make fuller and better use of animal products, and this "improvement in use" should be stressed and expanded. Meats, milk, ghee or clarified butter, wool, mohair, eggs, hides and skins, and bone and animal by-products are all mentioned.

A short description of an ideal native mixed farm is included and the authors conclude by describing briefly some of the more common ailments of stock. A glossary of terms is appended.

This little book will be found to be of service to teachers and children in native schools and to those who have to work amongst or are interested in native agriculturists. The authors are to be congratulated on the way in which they have dealt with and presented their subject.

E. H.

WITCHES' BROOM DISEASE INVESTIGATIONS

IV. Further Notes on the Susceptibility of I. C. Selections at River Estate to Witches' Broom Disease of Cacao

BY

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In an earlier paper of this series* observations were made on the susceptiblity of certain I. C. Selections to witches' broom disease at River Estate. In March 1943 these clones were again examined with the results shown below. The method used was the same as in 1942—the trees were cleared of brooms in November 1942 and in March 1943 all brooms were removed and counted and the results subjected to statistical analysis. It will be seen from the numbers of brooms removed that the disease has become considerably worse since March 1942 in this area, an observation confirmed by the fact that in 1943 loss of pods due to witches' broom disease became serious in this field for the first time.

SET I.—SUMMARY OF RESULTS—MARCH 1943, (TABLE I)

The results largely confirm those of previous years. Thus I. C. S. 4 which had most brooms in 1940/41 and in 1941/42 again had most brooms this year. I. C. S. 6 which had the least brooms in 1940/41 and was in the best group in 1941/42 has the smallest number of brooms again this year. The difference between the numbers of brooms removed from these two clones is less this year, but is still statistically significant beyond the 1% point. On the other hand there have been considerable changes in position in the order of merit between the clones which, on the basis of the first two years' figures, occupied intermediate positions on the list. I. C. S. 1 especially has shown a much greater susceptibility to cushion brooms than in the first two years. If we eliminate I. C. S. 5 as being too seriously damaged by cacao beetles to give reliable results, I. C. S. 6 and 8 remain the best in this set.

SET 2.—SUMMARY OF RESULTS—MARCH 1943, (TABLE II)

As last year I. C. S. 53 is the worst in respect of total brooms. I. C. S. 7 and 22 are still in the best group again with about half as many brooms as I. C. S. 53. In the case of I. C. S. 7 the apparent relative immunity may be due to the backward condition of the trees resulting from its susceptibility to cacao beetle. I. C. S. 45 is again in the best group as regards fan brooms, and moves this year from an intermediate position to the best group on total brooms, having relatively fewer cushion brooms this year. I. C. S. 1 which was in the best group last year in now in an intermediate position.

SET 3.—SUMMARY OF RESULTS—MARCH 1943, (TABLE III)

Here the results correspond very closely to the 1942 figures. I. C. S. 60 is still easily the worst clone; I. C. S. 12 is doubtful; I. C. S. 1 has become slightly worse to join I. C. S. 12; and I. C. S. 2, 9 and 98 show some resistance. I. C. S. 9 and 98 show considerable promise but I. C. S. 2 is very

* Baker, R. E. D. and Crowdy, S. H. Witches' broom disease investigations. II.—Notes on the susceptibility of I.C. Selections at River Estate to witches' broom disease of Cacao. *Tropical Agriculture*, XIX, 11, pp. 207-209, 1942.

TABLE I

Set 1.—Summary of Results—March 1943

Fan brooms			Cushion brooms			Total Brooms		
Clone	Mean brooms per tree	Difference	Clone	Mean brooms per tree	Difference	Clone	Mean brooms per tree	Difference
4	75.1	3.3	1	37.2	2.7	4	103.6	11.9
8	71.8	5.6	5	34.5	6.0	1	91.7	12.9
6	66.2	10.9	4	28.5	5.0	3	78.8	0.4
3	55.3	0.8	3	23.5	16.2*	8	78.4	3.4
1	54.5	14.0*	6	7.3	0.7	5	75.0	1.5
5	40.5		8	6.6		6	73.5	
Critical difference			Critical difference			Critical difference		
1 per cent. point ...	16.1		1 per cent. point ...	18.0		1 per cent. point ...	27.3	
5 per cent. point ...	12.5		5 per cent. point ...	13.9		5 per cent. point ...	21.2	

TABLE II

Set 2.—Summary of Results—March 1943

Fan brooms			Cushion brooms			Total brooms		
Clone	Mean brooms per tree	Difference	Clone	Mean brooms per tree	Difference	Clone	Mean brooms per tree	Difference
7	34.2	5.8*	53	45.2	25.2**	53	65.8	20.0**
22	28.4	2.6	1	20.0	1.0	1	45.8	7.4
1	25.8	3.6	45	19.0	2.8	16	38.4	0.4
16	22.2	1.6	16	16.2	12.4*	7	38.0	6.2
53	20.6	8.5**	7	3.8	0.4	22	31.8	0.7
45	12.1		22	3.4		45	31.1	
Critical difference			Critical difference			Critical difference		
1 per cent. point ...		7.1	1 per cent. point ...		12.9	1 per cent. point ...		16.5
5 per cent. point ...		5.5	5 per cent. point ...		10.0	5 per cent. point		12.8

TABLE III

Set 3.—Summary of Results—March 1943

Fan brooms			Cushion brooms			Total brooms		
Clone	Mean brooms per tree	Difference	Clone	Mean brooms per tree	Difference	Clone	Mean brooms per tree	Difference
60	26.4	9.0**	60	34.2	20.1**	60	60.6	32.3**
1	17.4	3.2	12	14.1	4.6*	12	28.3	1.4
12	14.2	0.8	1	9.5	7.6**	1	26.9	12.5**
98	13.4	0.4	2	1.9	0.9	98	14.4	0.8
9	13.0	7.4**	98	1.0	0.4	9	13.6	6.1
2	5.6		9	0.6		2	7.5	
Critical difference			Critical difference			Critical difference		
1 per cent. point ...		4.2	1 per cent. point ...		5.8	1 per cent. point ...		8.7
5 per cent. point ...		3.3	5 per cent. point ...		4.5	5 per cent. point ...		6.8

TABLE IV

Black figures show no change of position since 1942

Fan brooms				Cushion brooms				Total brooms			
Good ICS	Fair ICS	Poor ICS	Bad ICS	Good ICS	Fair ICS	Poor ICS	Bad ICS	Good ICS	Fair ICS	Poor ICS	Bad ICS
	6	7	**4**	**6**		3		**6**	3	1	**4**
	5										
	53		8	**8**		1			8		**53**
						5			**5**		
3	16		**60**	**7**		**45**	**4**	**22**	16	12	**60**
	2										
45	1			**22**		**16**	53	45	**7**		
	9			**98**		12	**60**	2			
	98			**9**				**9**			
								98			

backward, making little growth and severely attacked by cacao beetles. A regrading of the clones for disease resistance is shown in Table IV.

The I. C. Selections were made on the basis of yield and quality without any regard whatever to avoidance of witches' broom disease; they are presumably roughly representative of the seedling population of the island in this latter property.

It is therefore felt that the figures justify a hope that among the 100 clones there may be one or two that are self-compatible, good in respect of yield and quality of produce, and also somewhat less susceptible to witches' broom disease than the average of an ordinary seedling population. So far as the tests go yet Nos. 6, 8, 9, 45 and 98 show promise.

PYRETHRUM CULTIVATION IN KENYA *

THE cultivation of pyrethrum in Kenya has expanded very rapidly within recent years, the output having risen from 122,217 lb. in 1934 to 4,030,320 lb. in 1938.

This expansion is in large measure due to the high toxicity of the Kenya flowers which has enabled them to secure a premium on the world's markets, together with high average yields per acre and efficient methods of preparation and marketing of the product.

The chief conditions necessary for the successful cultivation of pyrethrum may be summed up as follows:—

(*a*) High altitude—over 7,500 feet, with evenly distributed rainfall of 40 to 45 inches. The highest yields in Kenya have been obtained on the top of the open ridges on the high altitude areas where yields as high as 1,200 lb. per acre of dry flowers per annum have been recorded.

(*b*) Soils on which weed growth is not excessively heavy, and on which the plants can obtain a firm root-hold.

(*c*) Absence of conditions likely to produce waterlogging.

(*d*) Moderate fertility—excessive fertility in the soil is likely to produce heavy growth, and growth of leaf at the expense of flowers, but some growers have made the mistake of planting the crop on poor soils with the idea of reducing weeding costs. This is, of course, a mistake as it will lead to reduced yields.

(*e*) Control of soil erosion. The crop is likely to suffer considerably from the effects of soil erosion and it is essential to take the necessary preventative measures such as contour ridging &c., more particularly where the soil is shallow.

(*d*) The establishment of a good stand in the field. An indifferent stand will never produce a full crop. When the stand becomes reduced, it is necessary to plough up the plantation and replant.

(*e*) Clean weeding. This is absolutely essential both within the plants themselves and in the rows between the plants.

Cultivation

Thorough cleaning and preparation of the land is essential, since it is not possible to perform thorough cultivation after the crop has been established and delayed attempts to eradicate weeds usually involve the removal of a considerable number of plants. Deep cultivation (in excess of 6–8 inches) does not appear to be necessary for the crop which is shallow rooted by nature and a reasonably firm bed is desirable before planting out so as to secure a good stand. When the land has been cleaned it should be contour terraced prior to planting in order to prevent erosion of soil. This is best effected by the construction of narrow base ridges which are on the usual variable grade recommended for arable crops, but in the case of exceptionally absorbent soil level base terraces may be employed. The banks should be approximately 5–6 feet wide and about 18–24 inches high with a shallow drain 3 feet wide on the upper side. Pyrethrum can be planted over the banks and their shape should be maintained when cleaning by drawing the soil upwards. It is estimated that a native can contour 30 yards of such a bank daily by hand with a jembie and shovel, so that the cost of protection per acre is relatively small.

Planting should be carried out in the main general direction of the contour ridges but provided the land has been adequately protected by ridges there is no need to plant exactly on the contour. By following the general line of the contours cultivation up and down slopes will be avoided.

Manurial Requirements

Experiments up to date have shown that little beneficial effect has been derived from the use of either organic or inorganic manures. A slight increase in yield of flowers was obtained in one year from the application of a top dressing of sulphate of ammonia, but at the present time there are no indications to show that the application of manures to the crop is likely to be beneficial although it appears that it may be deleterious.

* Abridged from an article by R. S. Ball published in *The Nyasaland Agricultural Quarterly Journal*, Vol. III, No. 1, 1943.

Planting Material

The two types of planting material used are either seedlings or root divisions from existing plants. A considerable diversity of opinion exists as to which are the best to use, but it would appear that it is usually easier to establish a field with seedlings since they have a better root system and withstand transplanting better under unfavourable conditions than divisions. At the same time, a considerable amount of labour and supervision is required for tending the seed beds and seedlings do not come into flower so quickly after transplanting as root divisions.

A.—Selection of root divisions

It is important to select material for root divisions carefully from high yielding plants, and this applies particularly at the lower elevations. The common practice of removing every plant over a certain area for purposes of obtaining root divisions should not be encouraged, but more attention should be paid to the selection of planting material. Material to be used for splitting should have all flowering stems cut off before it is dug up and attempts should not be made to obtain too many root divisions from one plant. Small spindly divisions with little or no root system will be found difficult to establish and replanting and patching subsequently will be necessary. Care should be taken to ensure that every split (division) when planted has part of the root system of the parent plant and contains a due percentage of foliage. A large number of individual plants should be used to establish a plantation and attempts should not be made to establish a plantation from one or two high yielding plants propagated repeatedly by root divisions. The reason for this is that the pyrethrum plant is self sterile and it is necessary to have a large number of individuals in the field so as to ensure adequate pollination which is necessary in order to obtain a high pyrethrum content in the flowers.

B.—Seedlings

Seedlings are generally used on account of the greater ease with which they can be established in the field, more particularly during unfavourable conditions and also the high cost of obtaining splits if it is necessary to buy when plants are not already available. It is of importance to use seed whose origin is known and which has been harvested from carefully selected material. Seed plots should be established from a large number of individual plants selected in the field for such characters as flower size (size of centres), number of flowers, upright non-struggling habit and high pyrethrum content and these should be planted all together in a plot by themselves and used for seed production. A large number of plants should be used for this purpose, so as to avoid any possibility of partial sterility through lack of sufficient numbers of individuals for cross-pollination.

The seed should be harvested when the disc florets have died and tend to fall off the flower head exposing the grayish-brown seed. It should not be stored for long periods as it loses its viability fairly rapidly. One pound of seed is usually adequate to plant one to one-and-a-half acres in the field. The seed does not usually germinate more than about 50 per cent. in the seed bed. Germination is slow and irregular taking about 12–14 days.

Seed Bed

The seed-beds should be made on well drained soil which is carefully and evenly levelled. Owing to the slow rate of germination of the pyrethrum seedlings, it is desirable to obtain a thorough germination of the weed seeds first before the pyrethrum seed is planted. Overhead shade should be provided for the seed-beds and it is advisable to thatch the soil itself with a light covering of grass until the seedlings have germinated. The seed should be scattered lightly over the beds and covered with a very thin layer of soil and watered daily. The grass covering will be removed at about the 12–14th day when the majority of the seed germinates. If any signs of damping off appear, the shade should be removed and the plants watered with water tinted with permanganate of potash. Pricking out of the seedlings about 3″ × 3″ apart is to be recommended, as this stimulates root development and will hasten the time at which they will come into bearing when transplanted into the field. Although this operation increases the labour costs, it is doubtless well worth while, since a return is secured much more quickly. The seedlings should be well grown before they are transplanted into the field and should have at least 10–12 leaves.

Transplanting into the Field

A considerable amount of experimental work has been carried out on the correct spacing for pyrethrum and it would appear that in the high altitude areas a square spacing of 2′ × 2′ is likely to give the most satisfactory results. On rich forest soils, however, where rooting is loose and weeding expensive, it is advisable to adopt a somewhat wider spacing between the rows, spacing the plants closer together in the rows. In this manner more mechanical cultivation with oxen and donkeys can be performed and there is less danger of loosening the roots of the plants. Under such conditions spacing of 2′ 6″ or even 3′ between the rows and 18″ between the plants in the rows are recommended.

At the lower altitudes (7,000–7,500 feet) where growth is not so vigorous a square spacing of 20″ × 20″ inches is recommended, except for rich forest soil conditions when the spacings adopted should be similar to those previously recommended.

The fields should be carefully marked out prior to planting and it may be desirable to leave paths at intervals to facilitate handling the crop. If,

however, wide spacings between the rows have been adopted, this will not be necessary, and even with a 2′ × 2′ spacing is not essential.

If the field is being planted with splits, an entrenching tool should be used for digging the holes prior to planting out. Great care should be exercised in splitting up the plants to ensure that each split has a part of the parent root system and the plants should be firmly planted in the ground and the soil well tramped round them. Carelessness in firming the soil round the roots of the plant is a frequent cause for a poor stand subsequently due to high mortality. In the case of seedlings, the holes can be prepared with a pointed stick, but care should be taken to ensure that the roots point properly downwards and soil is well consolidated round the plants. Approximately 10–14 boys will plant one acre daily, but it is work that requires the closest supervision and should not unduly be hurried. Failure to secure a good stand will result in low yield and a short life of the plantation. Fields established from splits should, at the high altitudes, commence to flower approximately 14 weeks after they have been planted, while seedling material will probably take about 8–12 weeks longer. There is a considerable difference of opinion as to the advisability of cutting off the flowering stems when the young plants begin to flower in order to stimulate their vegetative growth. Provided, however, good sized seedlings or splits have been used originally, there is no particular advantage in adopting this practice and picking of the flowers should commence as soon as possible.

Cleaning and Harvesting

As previously mentioned it is absolutely essential to keep the crop clean both from weeds between the plants and in the plants themselves. A certain amount of mechanical cultivation can be performed with small ox cultivators pulled either by an ox or a donkey, the latter being made more suitable for work between fairly close rows. While the plants are young, the majority of the weeding can be done in this manner, but care should be taken to remove all weeds growing in the plants themselves. On forest soils, where weed growth is heavy, it may be necessary to weed as frequently as every 14–17 days during the rains, but as a general rule the period varies from a month to six or more. The use of a Dutch or turnip hoe as opposed to the jembie for weeding is encouraged since it does not do much damage and it is quite effective for the work provided weeds are not allowed to grow much beyond the seedling stage, which is essential if the plantation is to yield well. Some farmers use Planet Junior hoes pushed by hand for weeding. These are quite effective for performing the work particularly in the early stages of the life of a plantation, but should not be used exclusively owing to their tendency to encourage the formation of a pan. An established plantation should be given at least one cultivation with ox cultivators annually to break up the soil on the surface which has become packed owing to the frequent treading during picking &c., and the operation is best performed immediately after the plantation has been cut back. The cultivators should penetrate about 2½ inches below the surface, but not deeper, otherwise they would tend to loosen the plants in the soil.

Failure to keep pace with weed growth will sooner or later necessitate thorough deep weeding, which will remove a large percentage of the plants. The acreage of pyrethrum which will be grown on any farm is therefore likely to be limited by the amount of labour available for cleaning and picking. Under average conditions one boy is continuously employed in cleaning approximately 5 acres, although this figure will vary very widely.

Picking

Flowers should be picked when there is no external moisture on them, either dew or rainfall, which is likely to cause heating before the flowers are dried. Such heating would be deleterious to the colour and appearance of the dried product and also to its pyrethrum content. For these reasons picking should not be commenced early in the morning until the dew has dried off the flowers. The flowers should be picked into wicker-work baskets which permit of access of air at the sides so as to prevent heating and if they are not removed to the drying plant for some time, should be spread out on tarpaulins when the baskets have been filled. The average amount of flowers picked per day varies from 25–30 lbs. wet flowers depending on the size of the crop and the labour employed. An amount considerably in excess of this may be picked during the periods of heavy flush. During the dry season the amount may fall to 12–15 lbs. daily.

Observations carried out showed that pickings may range as low as 9 lbs. per acre of dried flowers per picking to 250 lbs. per acre dried flowers per picking during the heaviest flush periods in high altitude pyrethrum growing areas.

Great care should be exercised over the picking operations so as to ensure that flowers only at the correct stage of maturity are harvested, *i.e.*, when 3–4 rows of disc florets are fully open, and that the picking of immature flowers and buds which would result in a lowering of the pyrethrum content, is avoided. The flowers should not be packed tightly in the receptacles into which they are picked, but allowed to fall in loosely. Payment for picking is usually made on the basis of weight. Picking is performed roughly at fortnightly to three weekly intervals throughout the flowering season which may continue for 9–10 months of the year. Flowers should be removed to the drier as rapidly as possible after picking.

Yields

Yields vary very greatly throughout the pyrethrum growing areas but are influenced largely by altitudes and the nature of the soil, the

highest yields being obtained at altitudes over 8,500 feet on soils which are of a medium loam character. Under these conditions, yields of 900–1,000 lbs. of dry flowers per acre per annum are obtained while at a lower elevation down to 7,000 feet yields in the neighbourhood of 500–600 lbs. of dry flowers may be expected. On rich forest soils with a very high humus content these yields will be lowered and probably an average for such soils at 8,000 feet will be in the neighbourhood of 550 lbs. per acre.

Life of a Plantation

The useful bearing life of a plantation will vary considerably with soil, altitude, rainfall and other factors. There are indications, however, that the pyrethrum content of the flowers may fall after about the fifth year since establishment, which would necessitate ploughing up and replanting. Except, however, in the highest altitudes the life of the plantation will probably be shorter than this since considerations of weeding, reduction in stand, compacting of the soil will probably render it desirable to replant before this age is reached. The chief indication of a need for re-establishment is a reduced stand with consequent severe reductions in yield and increased weeding costs. It is essential therefore that a definite replanting programme should be adopted every year, the percentage to be replanted being based on the average useful life of a field for the particular conditions obtaining. Thus on a loose forest soil where the useful life may be only three years it will be necessary to replant about 33 per cent. of the acreage annually, whereas in the high altitude areas on the top of the ridges 15–20 per cent. will be sufficient for annual replanting. Although it has not yet been proved definitely that pyrethrum content falls with increasing age yet it does appear that even if the original material is used for root divisions for replanting the content will again rise to its usual level indicating that soil factors are responsible. It is suggested that when pyrethrum has been removed from a plantation, it should not be replanted immediately but another crop such as wheat should be planted for a period of one year or more, so that weeds such as sorrel can be effectively destroyed and also other types of weed largely prevalent in pyrethrum. This will, of course, only be possible on the larger farms where sufficient land is available to adopt such a rotation, on the smaller farm it will be necessary to cultivate thoroughly, probably ploughing twice and then replant.

RUBBER FROM GUAYULE*

Introductory

The great need for rubber of any kind, and especially the need for some natural rubber, has intensified investigations into rubber-bearing plants and stimulated the production of the most promising ones. There are several such plants, both native and imported, which are capable of producing greater or lesser amounts of rubber. Outstanding among them, however, both in point of rubber production and developed methods of culture is guayule. Guayule rubber is the same kind of rubber as that produced by the Hevea tree of the East Indies, and while the two have slightly different properties in some respects they are readily interchangeable for most purposes. Guayule rubber makes excellent tyres, used either alone or in conjunction with other rubbers.

Guayule, *Parthenium argentatum*, is a shrub. It looks much like sagebrush, and grows wild in north-central Mexico and an adjacent area in the "Big Bend" section of Texas. The mature shrub is usually three feet or less in height, and has crooked, brittle branches. Its leaves are slender and grayish-green, with slightly irregular edges, and the many inconspicuous yellowish flowers are borne on short, slender stems.

In its native habitat, guayule grows generally on outwash fans of limestone soils, where the soil is light in texture and well drained. As indicated by its natural range it requires a mild climate, though dormant plants have withstood a temperature of 5°F. without being killed. It is very drought-resistant and can live where rainfall ranges from 10 to 15 inches per year. Like most other plants though, the better the growing conditions, the larger and faster it grows.

Unlike the Hevea rubber tree, where the rubber is contained in fluid form and is drawn off by tapping the tree, the guayule shrub deposits pure rubber in the cells of the plant itself, under the bark. It deposits the rubber when soil moisture begins to run short, so for most effective rubber production the plant requires a relatively short, wet growing season followed by a long dry period. This is the condition that obtains where the plant grows naturally, and that must be present where it is to be grown. If moisture is available for growth during too much of the year, little rubber is produced. Recent studies also indicate that cool temperatures, at least at night, are essential to rubber formation.

The guayule plant deposits some rubber each year of its life, and may live for twenty years or more. However, under cultivation the peak of production is reached during early maturity, and since the plant is destroyed in recovering the rubber, the most economical cropping period is four or five years. Under optimum growing conditions it will produce from 1,200 to 1,800 pounds of rubber per acre during such a period, the rubber contents

* Adapted from an article issued by the U. S. A. Department of Agriculture Forest Service.

ranging from 18 per cent. to 22 per cent. of the dry weight of the shrub. In case of need it may be harvested earlier, but with a corresponding reduction in yield.

The rubber occurs in both the branches of the plant and the roots, and extraction is accomplished by crushing and pulverizing the entire shrub and floating the rubber particles off on water.

History

The Indians of northern Mexico knew about guayule rubber and made some slight use of it before the advent of the white man. It was first noted scientifically, however, by J. M. Bigelow, M.D., in 1852, while attached to the Mexican Boundary Survey. He collected a specimen of the plant, which was later (1859) described and named by Professor Asa Gray. In 1876 an exhibit of guayule was sent from Durango to the Centennial Exhibition at Philadelphia, and in 1888 a New Jersey company imported a quantity of the shrub, from which it extracted the rubber.

It was not until 1904, however, that large-scale production of guayule rubber got under way, with the erection of processing plants in Mexico and Texas. By 1909, thirty million dollars of American capital was invested in the business, and the factories have exported some 4,000 tons of rubber annually. The figure for 1940 was 4,106, but this will doubtless be increased during the war. There is no longer a factory in Texas, but four of them operate in Mexico.

One of the early operators in Mexico was the Inter-continental Rubber Company. In 1912 the company decided to try domesticating guayule in the United States, and Dr. W. B. McCallum, Chief Botanist for the company, collected seeds from several hundred strains of the plant which he took to southern Arizona. There experimentation was started, looking both to improving the productiveness of the plant and to finding locations suitable for growing it commercially.

Later it was decided that the Salinas Valley of California offered the best climatic conditions for both continued experimentation and commercial production, and the operation was moved there in 1924-25. A mill capable of producing about 10,000 pounds of rubber per day was built, and since that time about 8,000 acres of guayule have been grown in the valley and processed in the mill. The rubber has been sold under the trade name "Ampar" and used for many purposes, including the manufacture of tyres.

Of much greater importance, however, is the fact that over the intervening 30 years, Dr. McCallum kept up an elaborate and painstaking experimental programme which has greatly increased the productiveness of the guayule shrub. The wild shrub, which of course is of all ages when harvested, turns out on the average about 10 per cent. of its dry weight in rubber, while the best of the improved strains make around 20 per cent. at five years of age. At the same time experiments were carried on to discover the strains best suited to various situations of growth. The hundreds of strains with which the research programme originally started have been reduced down to about ten, of which four produce the bulk of the actual planting stock.*

Cultivation and Harvesting

Guayule reproduces by means of seed, and seed collection is one of the vital elements of the cultural programme. The seeds are very fine, and are borne on slender, upright stalks. The Rubber Company had developed a mechanical seed picker, which utilizes the vacuum principle to suck the seeds up into a container. It is quite successful, though naturally somewhat wasteful of seed. During its first seed-collection campaign, the hand-picking methods were reverted to in order to get all the seed possible. More than 100,000 pounds was thus secured. The plant bears seed from its first year onward, and under proper growth conditions is a quite prolific seeder.

Guayule seed does not germinate readily if planted in its natural state, but a process of treatment before planting was finally evolved which results in germination of a satisfactory proportion of it.

After collection, the seed is run through a fanning mill to remove trash and chaff and is then placed in perforated drums which revolve in water. It is allowed to stay in this bath for 20 to 24 hours, when the water and sediment are drawn off and the bath refilled with a ½ per cent. to 1½ per cent. solution of calcium hypochlorite or sodium hypochlorite. The seed is soaked in this solution for from two to four hours, when it is again washed to remove the excess chemical and then put through a centrifuge to remove surplus water. It is ordinarily planted while it is still moist.

If the seed is to be stored it is dried when it comes from the centrifuge and stored in air-tight drums. It may also be stored as it comes from the field but must in any event be treated as already described before planting, unless it has been in storage for several years, when the treatment may be diminished or even dispensed with. Seed may be stored for several years without losing its viability, thus permitting a supply to be kept on hand against lean seed-production years.

The seed is planted in the nursery bed by an ingenious seeding machine which sows a complete bed—seven rows—at one time. The beds are four feet wide. Essentially, the machine lays the seeds on top of a finely prepared seed bed, then to keep them in place, lays a thin layer of white sand on top of them.

Immediately the bed is sown, it is wetted down with the sprinkling system and is sprinkled frequently thereafter until the plants are up and

* There is no reason to suppose that the limit has been reached in breeding up the plant in productiveness, or in adapting it to diverse growing conditions. Thirty years is a very brief time in which to improve a long-lived plant such as guayule.

have struck root. Thereafter they are watered less frequently, though they are always given sufficient water to keep them growing at the rate desired.

The beds must be kept free of weeds, and on new land this may prove to be a problem. While specially designed cultivating machinery cleans the space between the rows, weeds in the rows must be removed by hand.

Once the young plants become established they grow rapidly, and after four to five months are ready for transplanting. They are reduced to uniform height by a mowing machine which clips the tops, and are then loosened in the bed by a blade which is drawn along under the plants and shakes them loose. They are then pulled by hand, root-pruned to remove objectionably long roots, sorted, and the usable plants packed in boxes with wet moss or shingle-tow about the roots, for shipment to the field.

The seedlings are transplanted in the field by means of tractor-drawn planting machines, which plant four rows at a time. For each row a sub-surface tool opens a slot in the earth deep enough to accommodate the roots of the plants. Men on the machine—one for each row—feed seeedlings into mechanical fingers, which in turn insert them in the opened slot. A pair of packing wheels which follow close the slot and firm the soil about the roots. The rows are planted 28 inches apart and the plants spaced from 20 to 24 inches in the row depending upon the quality of the planting site and whether or not the land is irrigated. The machine plants about 10,000 seedlings per hour on the average, or 10 acres per 10-hour day.

Like any other row crop, guayule must be well cultivated and kept clean. While it does grow wild under certain favourable conditions of competition by other vegetation, it will not compete with weeds and grass on agricultural land and make sufficiently rapid growth to justify its occupancy of such land.

The shrub is harvested by a machine which digs out the plants, including the principal roots, and piles them up in a windrow. The windrow is then picked up by another machine, which chops the shrub and blows the chopped material into a truck-trailer, ready for transport to the factory. If it is desired to store the shrub for a time before processing, it may be baled like hay and stacked in any convenient place.

Guayule does not appear to have many important natural enemies. A few insects, notably grasshoppers and June beetles may do some damage to it, and some mammals, including sheep and goats, will eat the plant. It also is not subject to many diseases. The principal ones are certain root-rots, which ordinarily occur, however, only when the plant finds itself on heavy or poorly drained soil, and a crown rot which may appear if water stands around the plant. These diseases may be aggravated by any condition which prevents normal drying of the topsoil. Plants just emerging from the seed occasionally fall victim to the "damping off" fungus, common to a great variety of plants, but it generally is not serious in the nurseries.

Extraction of Rubber

When the chipped shrub is brought to the factory, it is put through a series of rolls and mangles which reduce it to a very finely shredded condition. This material, with a carefully controlled addition of water, is then fed into the upper end of a "pebble mill". The pebble mill is a long tube, lined with very hard silicon bricks and partly filled with a special kind of smooth pebbles. The tube rotates, and the material in it is thus ground between the pebbles and the lining, separating the rubber particles from the plant fibres.

Emerging from the lower end of the tube, the mass goes into a settling tank, where the water-logged woody material sinks and the rubber floats to the surface, the particles agglomerated in the form of "worms".

These worms are then put through certain cleaning processes, where the last of the plant fibres are removed. The rubber is spread out on trays and dried for three or four hours in vacuum driers, and then pressed into slabs about five inches thick, weighing 100 pounds. Two of these slabs are packed per box for shipping purposes.

Guayule rubber extracted by this process contains about 16 per cent. of resins. These resins are not mixed with the rubber in the plant, but become unavoidably mixed with it in the milling process. For some products the resin content is not objectionable; for others it must be removed or diminished. Tree rubber contains about 4 per cent. of resins. Since the war began, resins such as are obtained in guayule rubber have become valuable in the manufacture of plastics, so that the deresinating process, where it is necessary, may now pay its own cost.

JUTE SUBSTITUTE IN CUBA

It is understood that an experiment is being made in Cuba under Government backing to determine the commercial possibilities of *Malva blanca*, a plant which grows wild in Cuba and Venezuela. The fibre from this plant is claimed to be a good substitute for jute and can be made into bags for sugar, rice and coffee at a cost not greater than those made from jute. It is said that arrangements have been completed for the erection of a factory in Cuba for converting the Malva fibre into bags. This factory is expected to have an annual capacity of 6,000,000 bags.—(*Current Science*, Vol. XII, No. 1.)

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Cane Growth Studies: Factors Influencing Yields and Composition of Cane

Two otherwise identical culture experiments were made in Hawaii in two dissimilar climatic environments. One of these was at a station (Makiki) where the elevation is only 40 feet above sea level, and where bright sunny days with relatively few rainy days are the rule; the other was at a station (Manoa) where the elevation was 650 feet above the sea, with many rainy days and less than 50 per cent. of the sunlight received at the other station. Large amounts of soil were transported from the one station to the other, and *vice versa*, and the same varieties were planted in each soil at both stations. The experiment was continued through four ratoon crops. The yield of each crop was weighed and analysed. As was to be expected, the yields from all varieties at the station which enjoyed abundance of sunshine and a higher average temperature were much superior to the yields at the cloudy and cooler station. It turned out that the Manoa soil, when transferred to the more favourable Makiki environment, gave the largest yields, and showed itself to be better and richer than the native Makiki soil under the same conditions. This proves what has long been accepted; namely, that goodness of soil cannot of itself compensate for an unfavourable climate. Analysis of the crop showed that each soil had a more or less characteristic effect on the composition of the cane. Thus, the cane grown on Makiki soil had a higher concentration of both phosphate and potash in the crusher juice. Regardless of soil or of environment, the variety H 109 produced more cane and sugar than P. O. J. 2878 and Striped Tip, and P. O. J. 2878 outclassed Striped Tip, thus again showing that the relative "quantities of life" of plant varieties are generally independent of environment.—(*Sugar*, Vol. 37, No. 10.)

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Bagasse, a Chemurgic Raw Material

R. W. H. Hessey in an article in the *Proceedings of the Queensland Society Sugar Cane Technologists*, 1942, pp. 67-79, gives a general statement of the possible uses of bagasse and describes some experiments in the preparation of bagasse cellulose by the nitric acid process. For this purpose the bagasse is lightly shredded to pass a $\frac{1}{4}$ inch, but not a 1/20 inch, sieve. This bagasse fraction is boiled for four hours (under reflux) with a 2 per cent. solution of nitric acid, after which the crude pulp is filtered and washed. The most suitable method of purifying the crude pulp is to treat it at room temperature with a 9 per cent. solution of caustic soda for 2 minutes, and after washing, suspend it for 10 minutes in a saturated chlorine solution; finally the pulp is boiled with a 2 per cent. solution of sodium sulphite, filtered, and washed. The yield of purified pulp is around 33 per cent. and its alpha-cellulose content is 91.9 to 96.2 per cent.; the variation in alpha-cellulose content seems to be due to the variable quality of the bagasse, particularly as regards ash content. Experiments (not further described) show that furfural can be made from bagasse. This substance is an important solvent that has many and large uses. The source of furfural is the pentosan content of the bagasse, which averages about 25 per cent. from which the theoretical yield of furfural is 13.5 per cent. on dry substance. It is suggested that the production of plastics and furfural might be combined.

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Effects of Sulphur Deficiency on Citrus

Sulphur deficiency symptoms appeared in navel orange trees grown in granitic soil in 55-gallon containers and were very noticeable as abnormal yellowing of the new-cycle growth. Since these leaves had a higher nitrogen content than is normal it was possible to differentiate definitely between sulphur- and nitrogen-deficiency. Die-back occurred but otherwise no abnormal twig or bark symptoms. Growth was limited but there was profuse though weak bloom. Fruits were of a light yellowish-green colour and maturing fruits failed to develop a normal orange colour. Thickness of rind and lack of juice were noticeable. Analysis of sulphur-deficient leaves showed generally a higher nitrogen, phosphorus, potassium and magnesium content and a lower calcium and sulphur content than normal comparable healthy leaves. It seems unlikely that local orchard soils would benefit from sulphur application.—(*Horticultural Abstracts*, Vol. XIII, No. I, 1943.)

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Effects of Phosphorus Deficiency on Citrus

Young navel orange trees were grown in a calcareous, fine sandy loam in 55-gallon containers and supplied with nitrogen and potassium but no phosphorus. The first symptom of malnutrition was noticed 3 years after planting, when an abnormal shedding of leaves occurred after the spring bloom. Some leaves showed burned areas, and many had a dull green, bronzed, lustreless appearance (which is illustrated in colour). Little new growth followed and the leaves were undersized. Spring blossoms in the two succeeding years were meagre and fruit almost entirely failed to set. There were few other abnormal symtoms. A secondary manganese deficiency developed in the phosphorus-deficient trees. It is noted that trees growing in the open on comparable soils showed no phosphorus deficiency symptoms, which indicates that the deficiency in the experimental cultures was partly the result of restricted root development.—(*Horticultural Abstracts*, Vol. XIII, No. I, 1943.)